AD-A079 598 ARIZONA UNIV TUCSON DEPT OF ELECTRICAL ENGINEERING F/G 20/14
EXPERIMENTAL INVESTIGATION OF ELECTROMAGNETIC PULSE (EMP) PROPA--ETC(U)
NOV 79 R N CARLILE AFOSR-76-2949

UNCLASSIFIED AFOSR-TR-80-0001 NL

1 OF 1
AD
A079598

END
DATE
FILMED
2-80
DDC

Experimental Investigation of Electromagnetic Pulse (EMP) Propagation in a Conduction Plasma

12

Final Report

Contract 26-2949

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

LEVEL

For the period

1 October 1978 - 30 September 1979

Prepared by

R. N. Carlile, Principal Investigator
Department of Electrical Engineering
University of Arizona
Tucson, Arizona 85721

November 29, 1979

ENGINEERING EXPERIMENT STATION
COLLEGE OF ENGINEERING
THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER (19) (18) AFOSR-TR- 80-0001	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) (6) EXPERIMENTAL INVESTIGATION OF ELECTROMAGNETIC PULSE (EMP) PROPAGATION IN A CONDUCTION PLASMA,	5. TYPE OF REPORT & PERIOD COVERED Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) R. N. Carlile	8. CONTRACT OR GRANT NUMBER(s) (15) AFOSR-76-2949
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Electrical Engineering, University of Arizona, Tucson, Arizona 85721 (17) A8	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F (16) 2301
11. CONTROLLING OFFICE NAME AND ADDRESS AFOSR/NP, Bolling AFB, Bldg. 410, Washington, DC 20332 (12) 20	12. REPORT DATE (11) 29 Nov 79
	13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(9) Final rept. 1 Oct 78-30 Sep 79,

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The electromagnetic pulse (EMP) generated by a nuclear detaonation has been the subject of extensive study. Computer codes have been developed which attempt to model the generation and propagation of the EMP due to both a high altitude and low altitude detonation. In some of these codes, the current density term which appears in Maxwell's equations due to conduction currents of secondary electons is modeled as a function of conductivity which is spatially and time dependent. A more complete description of the conduction currents is given by the familiar fluid transport equations for mass, momentum and energy, which are

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 403 696

collectively called the swarm equation.

Accession For	
NTIS GRA&I	☒
DDC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist. A	Avail and/or special

Final Report

Grant 76-2949

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Air Force Office of Scientific Research
Bolling Air Force Base
Washington, D. C. 20332

1 October 1978 - 30 September 1979

R. N. Carlile, Principal Investigator
Department of Electrical Engineering
University of Arizona
Tucson, Arizona 85721

November 29, 1979

This is a final report on work conducted under AFOSR Grant 76-2949 for the four year period from October 1, 1975 through September 30, 1979. This work was done in the Plasma Laboratory in the Department of Electrical Engineering at the University of Arizona. The scope of the work can be placed under two headings: 1) Absorption of energy from a transient electromagnetic pulse (EMP) as it propagates through a plasma; and 2) anamlous enhanced ionization of an N_2 plasma by an EMP.

In Section A, we discuss the work done under this Grant, and in Section B, we list publications, conference presentations, and a report which have been a consequence of this work.

A. Work done under Grant 76-2949

The electromagnetic pulse (EMP) generated by a nuclear detonation has been the subject of extensive study. Computer codes have been developed which attempt to model the generation and propagation of the EMP due to both a high altitude and low altitude detonation. In some of these codes, the current density term which appears in Maxwell's equations due to conduction currents of secondary electrons is modeled as σ E, where σ is a conductivity which is spatially and time dependent. A more complete description of the conduction currents is given by the familiar fluid transport equations for mass, momentum, and energy, which are collectively call the swarm equations.

Although these models are used by many workers, no work had been done to check their validity. We saw that it would be possible to do some simple experiments in the laboratory to achieve this goal, and so this was the motivation for the work of this Grant.

1. Absorption of Energy from a Transient Electromagnetic Pulse (EMP) as it Propagates Through a Plasma.

Initially, we constructed a machine in the Plasma Laboratory in the Department of Electrical Engineering at the University of Arizona which would allow a pulse with the features of an EMP to propoagate along a parallel plate waveguide which was filled with plasma. This machine is shown in Figure 1. We were interested to see how the EMP applied to the input of the waveguide would be modified when it appeared at the output. We would then compare this output pulse with the predictions of the swarm equations, and thus test the validity of these equations. It should be mentioned that the swarm equations (and also Maxwell's equations) were transformed to a retared time frame according to the prescription proposed by Karzus and Latter, and so were valid for a time comparable to the input EMP pulse length, about 2 nanoseconds.

The initial measurements and comparisons with theory are described in some detail in Paper 1 in Section B and the reader is referred to that reference. Also, the experimental system of Figure 1 is discussed in that reference. In summary, we found that agreement was good between theory and experiment as long as the N_2 gas pressure and electron number density n were low; however, whenever one and particularly when both of these parameters was increased by an order of magnitude, significant disagreement occurred.

In these measurements, we only observed the output at early times; also, the gas pressure was quite low, corresponding to above 100 KM altitude. We were limited to these low pressures because of the method by which we produced the plasma. We then embarked on a program to develop a baffle which would allow differential pumping of the system, and would allow us

to increase the pressure to over 100 microns, corresponding to an altitude of about 60 KM, which is a much more interesting altitude than 100 KM. This baffle is successful and creates a pressure differential of 100:1. It is described in a paper which is being prepared. (See Paper 7 in Sec. B).

In some preliminary measurements, we increased the pressure to 12, 25, and 50 microns of N_2, and observed the pulse output for relatively large values of ambient electrons number density n. The results for these three cases are shown in Figures 2, 3 and 4. We may observe in these Figures that although the input pulse length is only 2 nanoseconds, as shown in Figure 5, that a signal is emitted from the output for up to 15 nanoseconds. This is a consequence of the highly dispersive nature of the plasma. Note that, as discussed in Paper 1 in Section B, there is a longitudinal DC magnetic field which contributes to the dispersive property of the plasma.

Also shown in Figures 2, 3, and 4 is the prediction of the swarm theory, which is only carried out for a few nanoseconds, which is consistent with the early time approximation that has been built into this theory. This theory should be particularly capable of predicting this first peak accurately. However, the theory seems to be in error due to an inherent failure of the fluid model which underlies the swarm equations.

The results of these measurements are being submitted for publication. (Paper 2, Section B).

We have now continued these measurements over a wide range of pressure and n, and continued to find major discrepancies between our measurements of the first peak of the output and the predictions of the swarm theory. The results of these measurements are summarized in Figures 6 and 7.

These graphs show some interesting features of the discrepancy:

(1) At large values of n, (with a peak value above 5 x 10^9 cm^{-3}), the theory predicts too large a peak, while at lower values of n, the theory predicts too low a peak;

(2) As the pressure increases, the percent discrepancy between the measured and predicted first peak amplitude increases. We intend to present these results in a paper currently being prepared. (Paper 4 in Section B).

2. Anamolous Enhanced Ionization of an N_2 Plasma by an EMP.

In order to obtain some understanding of what could be causing the discrepancy between theory and experiment discussed above, we started to consider other simple experiments that we might do. In the region of high n, where the experimentally measured first peak maximum lies below that predicted by the theory, it occurred to us that perhaps there might be more electrons present in the plasma that are predicted by the swarm model. To test this concept, we placed a Langmuir probe in the plasma. We observed that when the EMP travelled down the waveguide, there would be a sudden increase in n which was readily detected by the Langmuir probe. A typical plot is shown in Figure 8. In that Figure, the number density increases by 85%. Based on the Townsend coefficient, which is inherent in the swarm theory, the number density should increase by less than 1%. Thus there is a significant and unexplained increase in n, which we call anamolous enhanced ionization.

We need to confirm that what we are measuring is indeed associated with increased number density of electrons. We have removed the plasma and found that this effect then disappears as it should. We note in

Figure 8 that the fall time of the pulse is about 0.1 millisec., which is about the length of time that we would expect the plasma to be confined in the system. The confinement time is controlled by ion diffusion out the ends of the system. Finally, the rise time is much too slow to be due to the EMP, since as we have seen, the EMP at a point in the waveguide lasts a maximum of 20 nanosec. However, the rise time is about the same as the RC time constant of the measurement system. Thus, we theorize that the rise time of n is really much faster that indicated in the Figure 8.

This data is incomplete. We need to do two things:

(1) Make a much more extensive measurement of this effect at the full range of parameters available in our system;

(2) Do an interfereometer study of the electron density rise time. By using an interfereometer, it is possible to make a direct measurement of the rise time, and at the same time, establish once and for all that what we are seeing is an increase in n in the plasma due to the EMP.

B. Papers and conference presentations resulting from this grant

Paper Published

1. Carlile, R. N., and Alexander Cavalli, William L. Cramer, Richard M. Hyde, and William A. Seidler, "Absorption of Energy from a Large Amplitude Electromagnetic Pulse by a Collisionless Plasma", IEEE Trans. on Antennas and Propagation AP-27, 596, Sept., 1979.

   Abstract - A series of experiments in which an electromagnetic pulse (EMP) is propagated through a nitrogen plasma are discussed. The pulse has the general characteristics of an EMP. The pulse is observed as it emerges from the plasma as a function of the plasma parameters. As the electron number density increases, it is found that energy is increasingly absorbed from the pulse, a process due to joule heating. In addition, at higher number densities, ringing of the pulse occurs. The nitrogen pressure in these experiments is sufficiently low so that collisions play only a minor role. Also developed is a theoretical model based on the fluid transport equations. This theory predicts that the electrons of the plasma are attaining a temperature of about 15 eV in that part of the system where the dc magnetic field is about 80 G. More importantly, it is able to predict the output pulse quite well under the conditions that the ambient nitrogen pressure and the electron number density are low. The theory appears to fail as these parameters are increased.

Paper Ready for Publication

2. Carlile, R. N. and Alexander Cavalli, "A Note on the Absorption of Energy from an EMP by a plasma at a Moderate Neutral Pressure", to be submitted to the IEEE Trans. on Antennas and Propagation.

Papers in Preparation

3. Carlile, R. N. and Alexander Cavalli, "Propagation of an EMP through a Collisional Plasma," to be submitted to IEEE Trans. on Antennas and Propagation.

4. Carlile, R. N. and Alexander Cavalli, "A Simple, Inexpensive Laboratory Plasma Machine", to be submitted to the IEEE Trans. on Plasma Science.

5. Carlile, R. N. and Alexander Cavalli, "Anamolous Enhanced Ionization of a N_2 plasma by a Transient Electromagnetic Pulse", to be submitted to the IEEE Trans. on Antennas and Propagation.

6. Carlile, R. N., "Computer Simulation of the Propagation of a EMP Through a Plasma", to be submitted to the IEEE Trans. on Antennas and Propagation.

7. Carlile, R. N. and Alexander Cavalli, "A Structurally Simple Baffle which Allows Differential Pumping of a Vacuum System", to be submitted to the Review of Scientific Instruments.

8. Carlile, R. N., "The Evolution of the Electron Distribution Function in Time for Electrons in the Presence of a Transient Electromagnetic Pulse", to be submitted to the IEEE Trans. on Plasme Science.

Conference Papers Presented

1. Carlile, R. N. and W. A. Seidler, "Experimental Investigation of the Absorption of Energy from an EMP Propagating Through a Plasma", presented at the AP/USNC/URSI Meeting at Stanford University, June 20-24, 1977.

2. Seidler, W. A., "A Technique to Predict Nonlinear Propagation of Intense Electromagnetic Pulses Through Weakly Ionized Plasmas", presented at the AP/USNI,URSI Meeting at Stanford University, June 20-24, 1977.

3. Cavalli, Alexander, Carlile, R. N., and W. A. Seidler, "Experimental Investigation of the Absorption of Energy from an EMP by a Plasma with a High Collision Frequency", presented at the NEM, 1978 Conference at the University of New Mexico, Albuquerque, NM, June 6-8, 1978.

4. Carlile, R. N., A. Cavalli, and W. A. Seidler, "Observation of Low Frequency Energy Tail Following in the Wake of an EMP Emerging from a Plasma", presented at the NEM, 1978, Conference at the University of New Mexico, Albuquerque, NM, June 6-8, 1978.

5. Carlile, R. N., A. Cavalli, W. L. Cramer, M. E. Dunham, and W. A. Seidler, "Electromagnetic Pulse (EMP) Propagation Through a Plasma", presented at the USNC/URSI Meeting, June 18-22, 1979, Seattle, WA.

6. Carlile, R. N. and Alexander Cavalli, "Absorption of Energy from an EMP by a Plasma at a Moderate Neutral Pressure", presented at IEEE Annual Conference on Nuclear and Space Radiation Effects, July 17-20, 1979, at the University of California at Santa Cruz, Santa Cruz, CA

Scientific Report

Seidler, W. A., "Quasi-linear Propagation of Electromagnetic Pulses in the University of Arizona Plasma Fascility", Report FR-20055, Simulation Physics, Inc., March, 1977.

FIGURE CAPTIONS

1) The experimental system

2) The electric field versus time at the output of the experimental system. Pressure, 12 micron N_2; peak electron number density, 2.5×10^9 cm^{-3}.

3) The electric field versus time at the output of the experimental system. Pressure, 25 micron N_2; peak electron density, 6×10^9 cm^{-3}.

4) The electric field versus time at the output of the experimental system. Pressure, 50 micron; peak electron number density, 7×10^9 cm^{-3}.

5) The input pulse, electric field versus time.

6) Maximum of first peak of output electric field versus peak of electron number density. Pressure, 50 micron N_2.

7) Maximum of first peak of the output electric field versus pressure. Peak electron number density, 2.5×10^9 cm^{-3}.

8) Increase in the electron number density versus time.

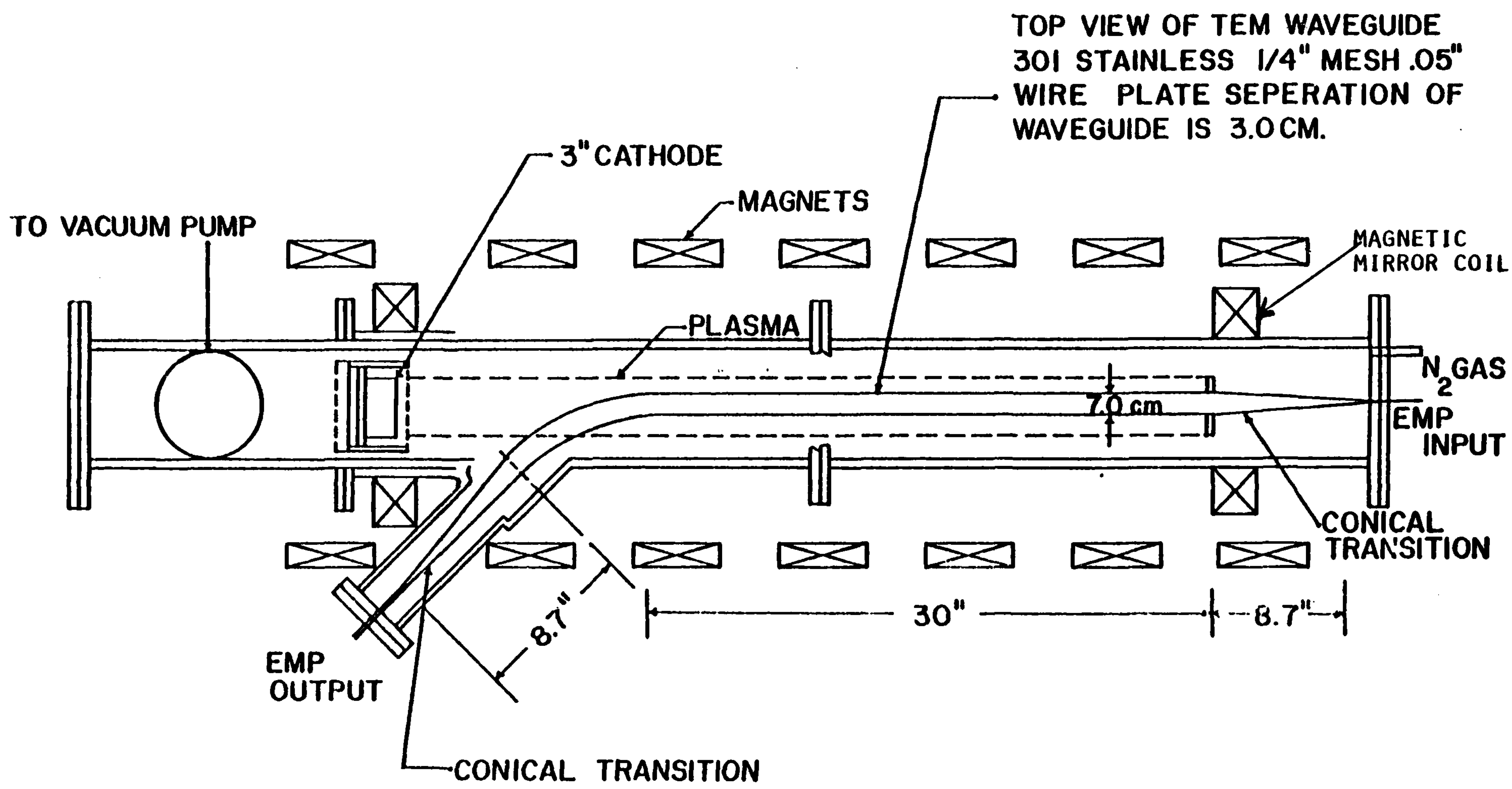

TOP VIEW OF TEM WAVEGUIDE
301 STAINLESS 1/4" MESH .05"
WIRE PLATE SEPERATION OF
WAVEGUIDE IS 3.0 CM.
3" CATHODE
MAGNETS
TO VACUUM PUMP
MAGNETIC
MIRROR COIL
PLASMA
N2 GAS
7.0 cm
EMP
INPUT
CONICAL
TRANSITION
8.7"
30"
8.7"
EMP
OUTPUT
CONICAL TRANSITION

Fig. 1

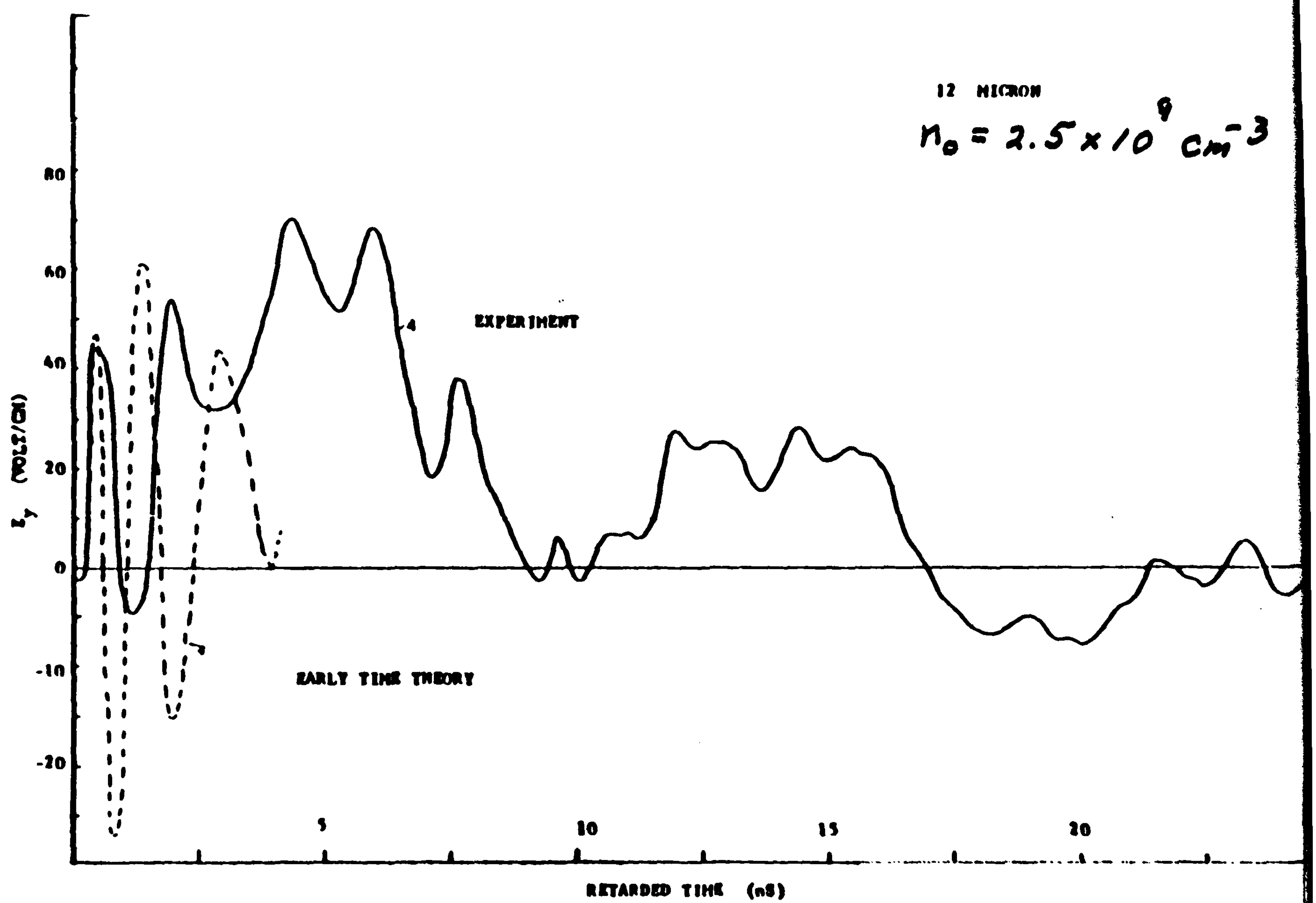

12 MICRON
$n_o = 2.5 \times 10^9\ cm^{-3}$
80
60
40
20
0
-10
-20
E_y (VOLTS/CM)
EXPERIMENT
EARLY TIME THEORY
5
10
15
20
RETARDED TIME (nS)

Fig. 2

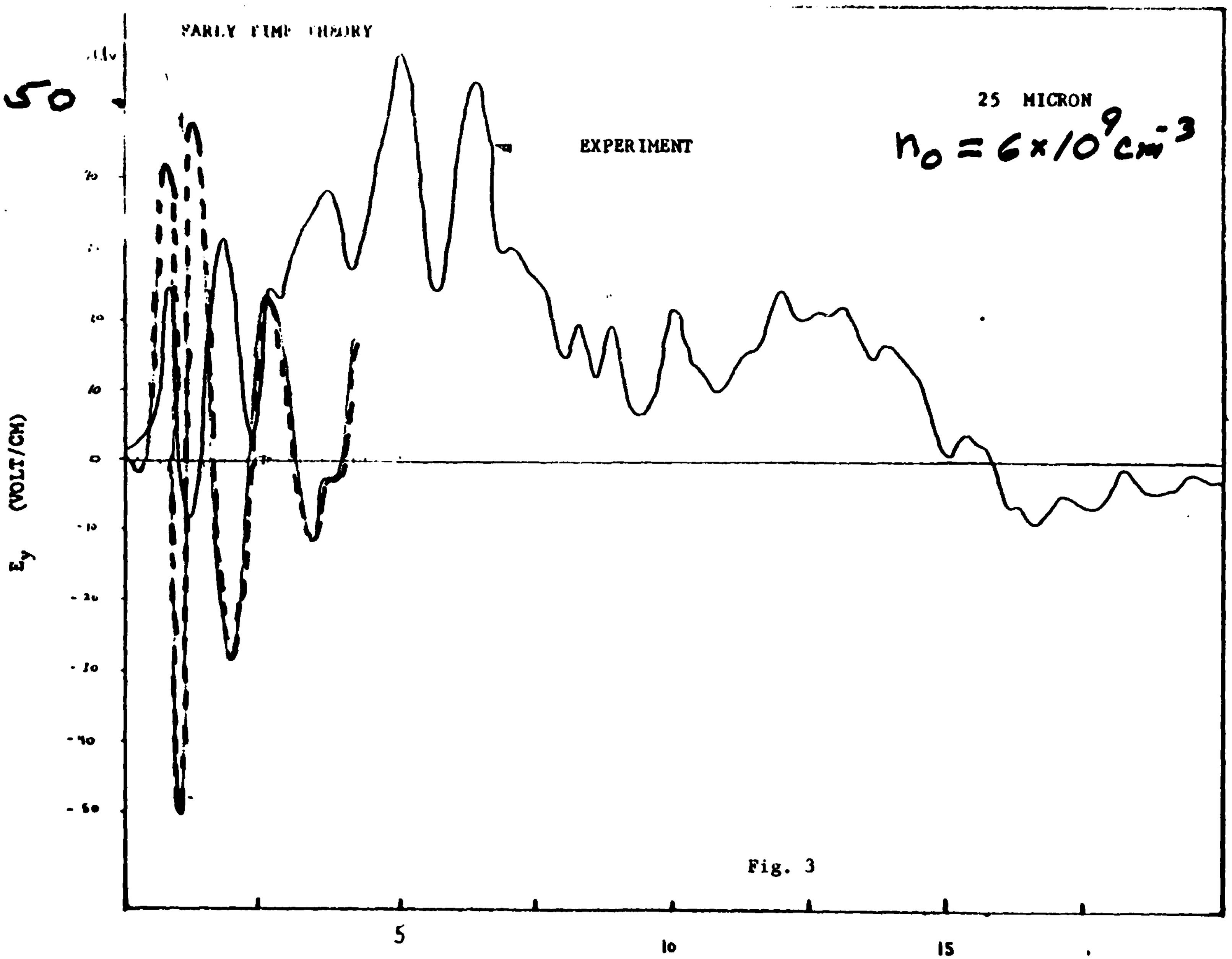
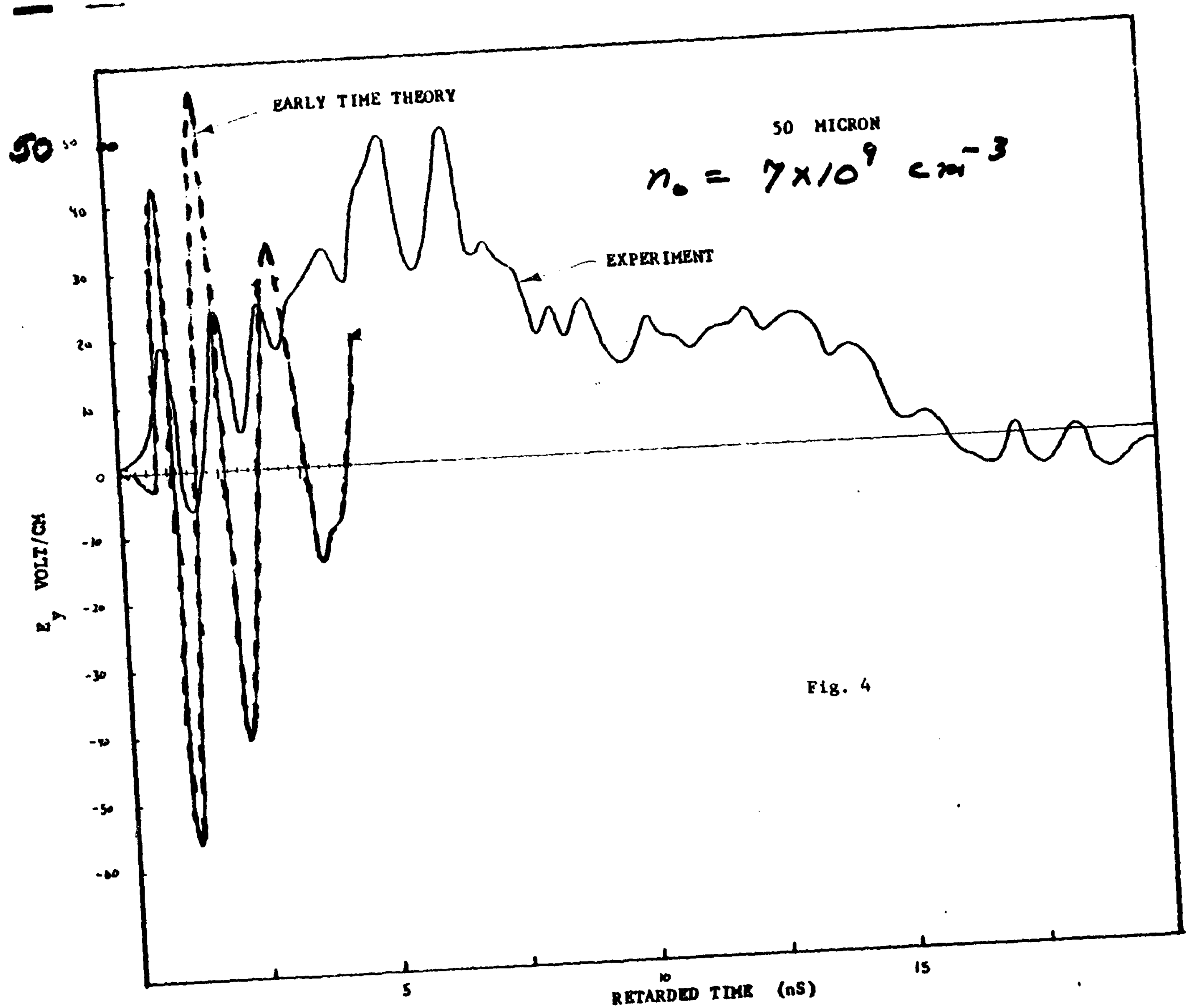

EARLY TIME THEORY
EXPERIMENT
25 MICRON
$n_0 = 6 \times 10^9 cm^{-3}$
E_y (VOLT/CM)
50
0
5
10
15

Fig. 3



EARLY TIME THEORY
50 MICRON
$n_0 = 7 \times 10^9\ cm^{-3}$
EXPERIMENT
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
E_y VOLT/CM
5
10
15
RETARDED TIME (nS)

Fig. 4

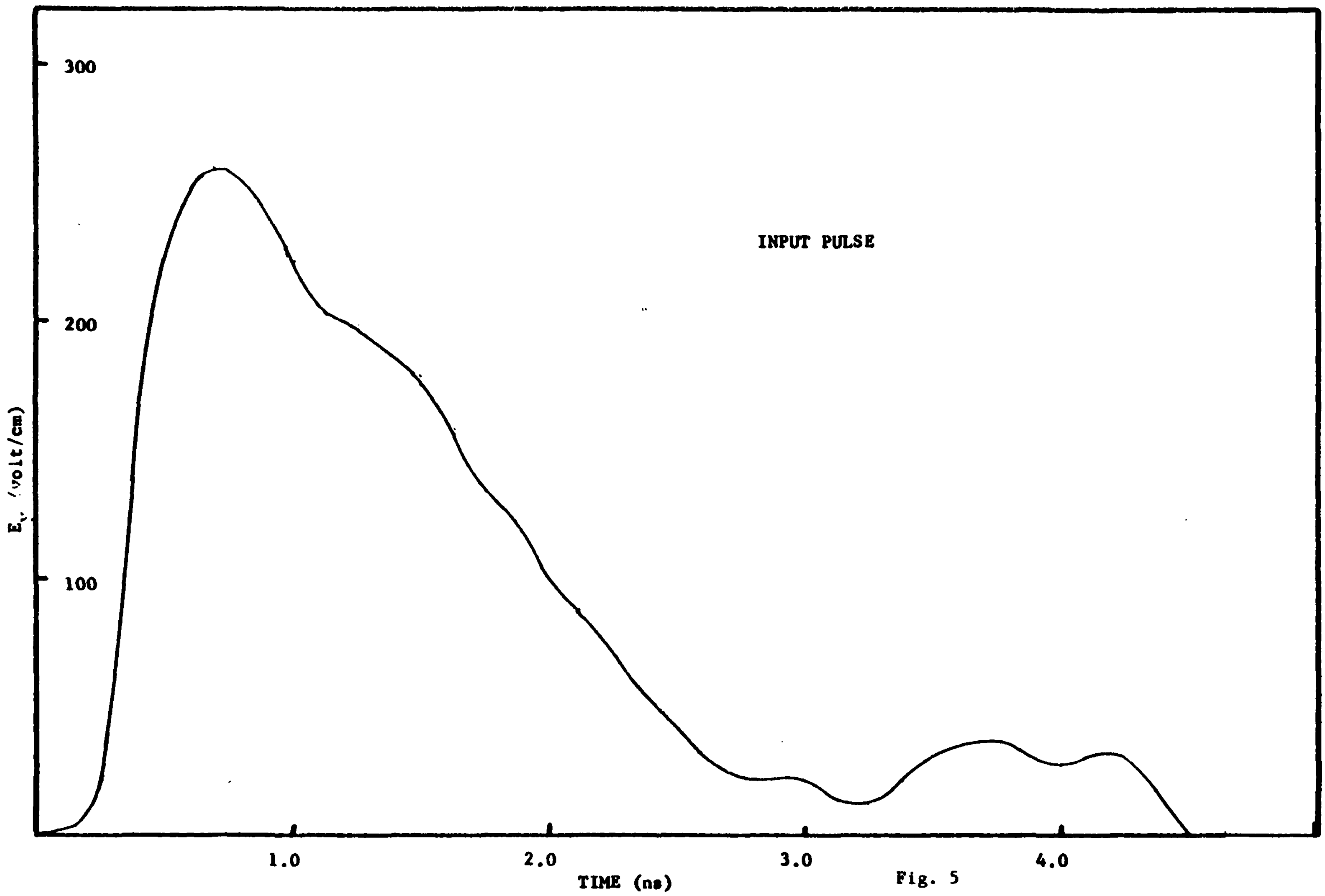


Fig. 5

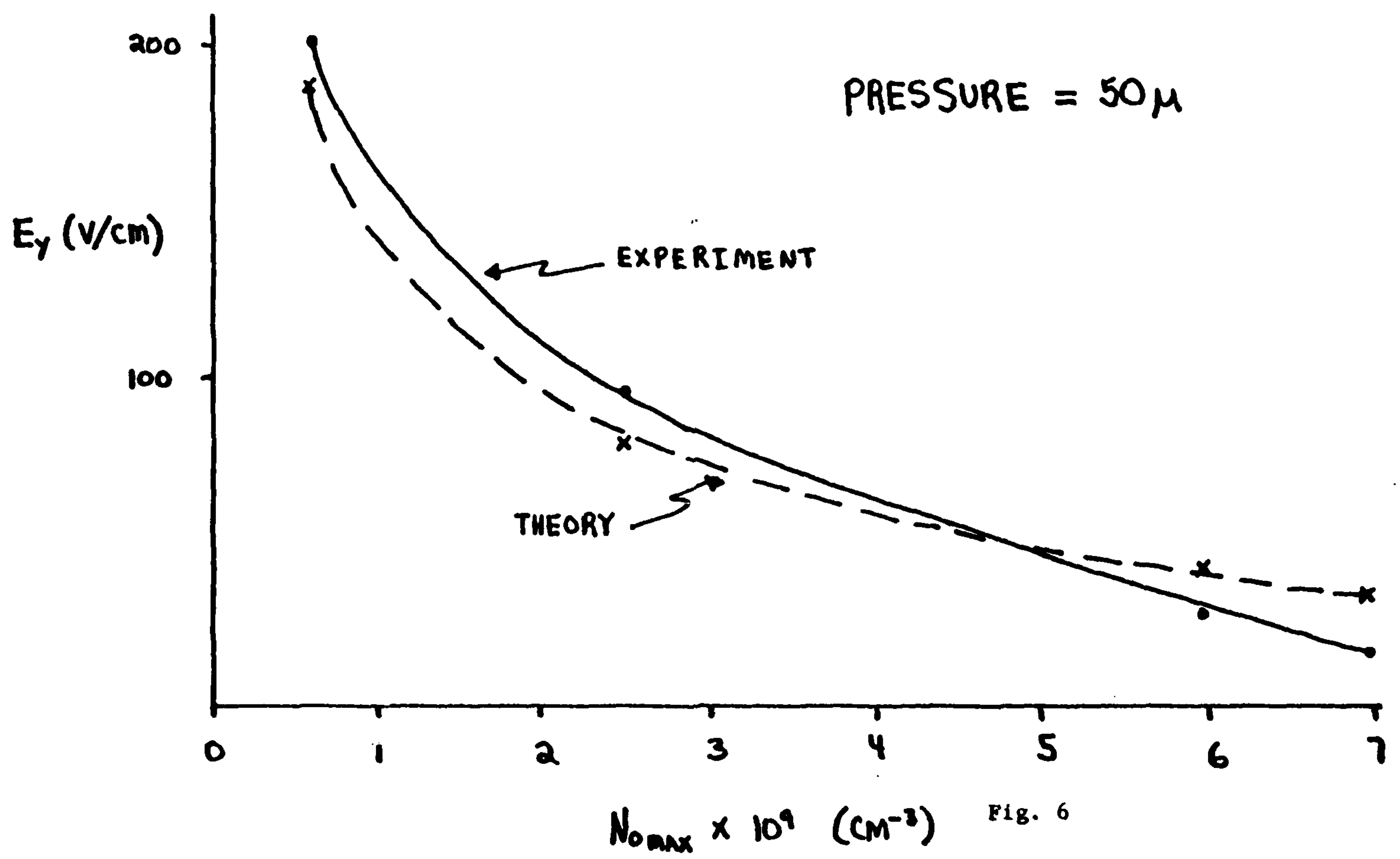
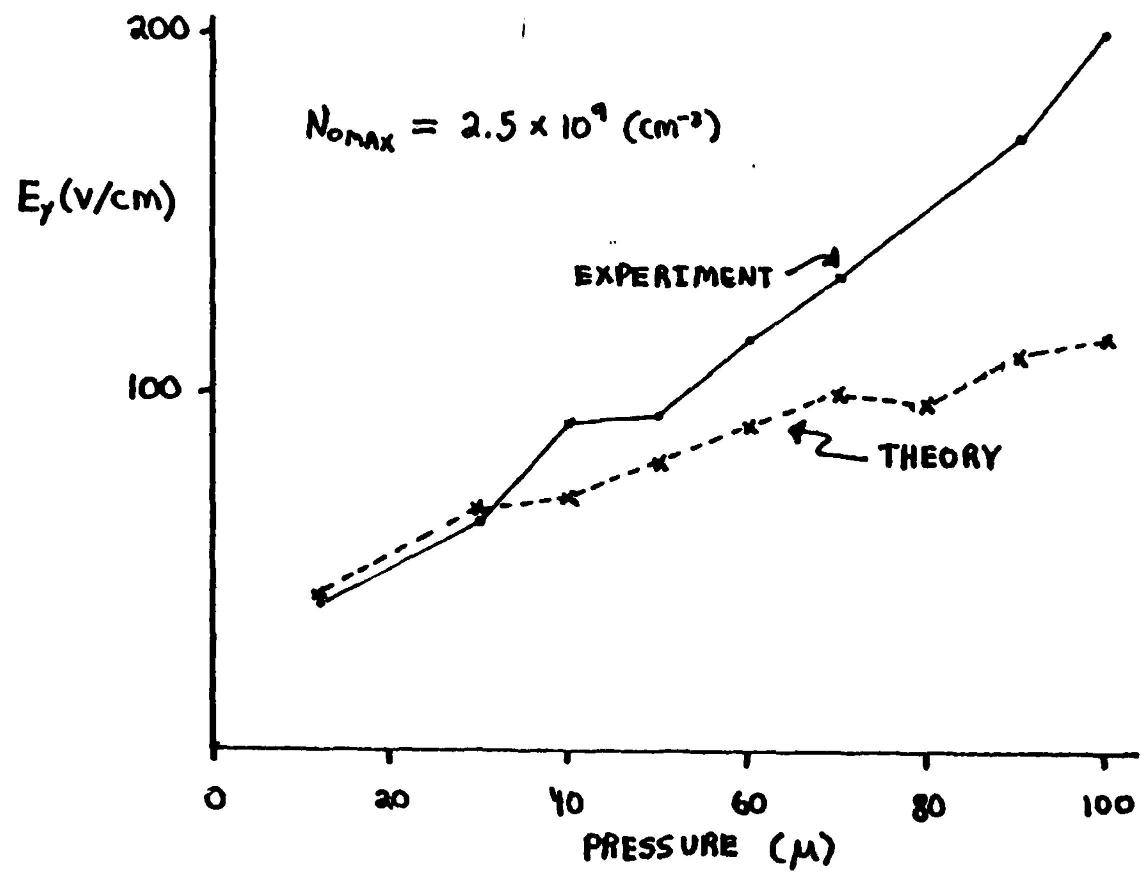

200
100
E_y (V/cm)
PRESSURE = 50μ
EXPERIMENT
THEORY
0
1
2
3
4
5
6
7
$N_{o\,max} \times 10^9$ (CM^{-3})

Fig. 6



$N_{o max} = 2.5 \times 10^9$ (cm^{-3})
E_y(v/cm)
200
100
EXPERIMENT
THEORY
0
20
40
60
80
100
PRESSURE (μ)

Fig. 7

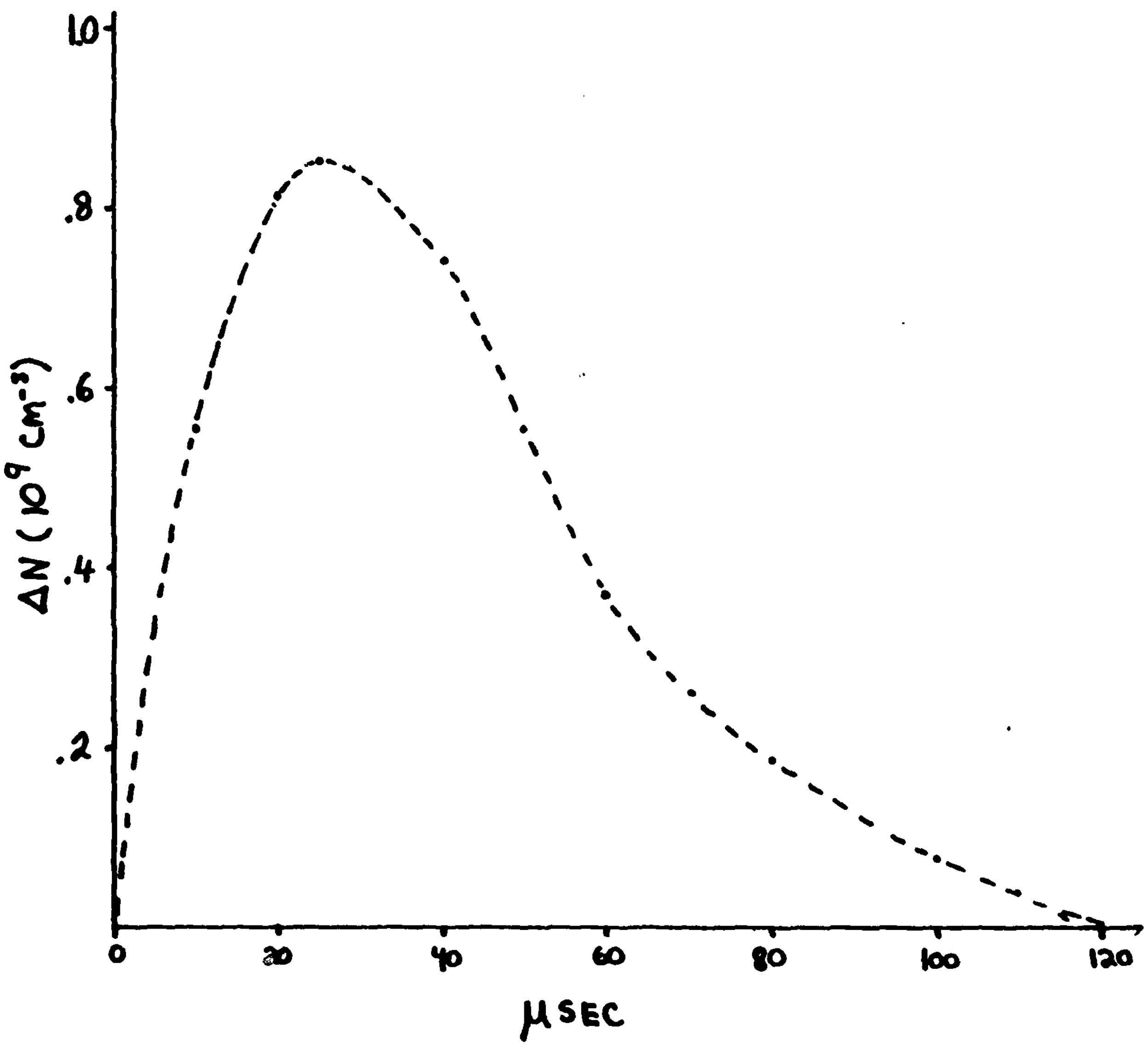


Fig. 8